Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 81 (2019) 803–808

www.elsevier.com/locate/procedia

52nd CIRP Conference on Manufacturing Systems

Developing an Augmented Reality Based Training Demonstrator for Manufacturing Cherry Pickers

Francesca Ferrati, John Ahmet Erkoyuncu*, Samuel Court

Through-life Engineering Services Centre, Cranfield University, MK43 0AL, UK.

* Corresponding author. Tel.: +44 (0) 1234 754717; *E-mail address:* j.a.erkoyuncu@cranfield.ac.uk

Abstract

This paper presents an Augmented Reality (AR) demonstrator to test its feasibility with enhancing the training process, improving learning time and error rate. The application environment was a manufacturer of cherry pickers. The demonstrator focused on covering the assembly of hydraulic hoses to the relative valve; the choice was driven by Company needs. Requirements led to the choice of Microsoft HoloLens as hardware, while Unity and Vuforia were used as software. The demonstrator provides sequential instructions through texts, images and animations. Results showed improvements when introducing AR for error rates and for the average assembly times.

Keywords: Augmented reality; training; manufacturing

1. Introduction

The project was conducted through an MSc thesis project in collaboration with a cherry picker manufacturer in the UK. The relatively high-value cherry pickers are typically assembled within a 48 hour duration. The challenge observed was with the inefficiency in the training process, raising the possibility to introduce new technologies to improve its efficiency. The major targets are to reduce the significant amount of time that the expert technicians spend on delivering training and the relative costs. Costs are directly correlated to the amount of time required to assemble cherry pickers.

Among possible technological solutions, a valid option was considered as Augmented Reality (AR). AR is a powerful technology that allows human-computer interaction, displaying information/holograms on the real world context. It has found several applications within the industrial and manufacturing fields. In the context of training enhancing efficiency through overlaying information directly on the machine on which operators work has been a popular approach [1]. This is achieved by providing full guidance independently from the trainer, and operators can learn while performing operations [2]. Since AR leaves the world intact and does not prevent the user to see it, safety risks related to the manufacturing environment can be significantly reduced compared to Virtual Reality (VR) solutions.

1.1. Project focus

The research project aimed to develop an AR demonstrator that can test the applicability of AR within the cherry picker manufacturing context and its effectiveness in addressing training inefficiencies. The work intended to study the Company context and environment, to identify its specific requirements and to develop an AR demonstrator suited for the specific manufacturing processes. Developing a bespoke solution was needed, to assess the applicability of AR within this companies' industrial environment, which cannot be evinced solely from previous applications. The focus was on speeding up the training process, without affecting its quality.

The main contributions of the paper are:

- An AR based architecture for training in manufacturing
- Evidence of the potential benefit AR can offer for training

10.1016/j.procir.2019.03.203

2. Literature review

VR technologies completely immerse a user in an artificial environment, which prevents from seeing the real world. In contrast, AR superimposes virtual objects, enhancing users' perception and displaying additional information. Users can combine augmented information with the specific practice, which is a key element to enhance learning [3]. AR offers advantages compared to VR, which requires modelling the whole working environment, a complex and time- consuming activity [4]. AR finds several applications in the manufacturing field by providing context-based information [5]. AR can support industrial training by projecting assembling or disassembling instructions directly on to the machines on which operator's work [6].

AR can be visually displayed in three ways: video see-through, optical see-through and projective displays. With the video see-through technique, a video replaces reality and AR enables overlaying upon it and the user's view is completely digital. Conversely, the real world is left untouched with the optical see-through and AR enables overlaying on it. With projective displays, AR is cast directly on real objects [7]. Visual information displayed can be texts, virtual elements (such as arrows, images, videos, icons or symbols) or 3D object's models [8].

The tracking and registration enable the alignment between the user view and the real world. Marker-based and marker-less solutions are available, making it possible to introduce AR within a manufacturing shop-floor contexts. Since AR systems are capable of recognising objects and components (either through feature- based or model-based tracking methods), users can potentially move in the AR environment and manipulate objects intuitively and naturally. Marker-less solutions can be suitable for non-prepared environments when work is performed on a new machine each time [9].

2.1. AR for training

AR has been demonstrated to be a valid solution for training within certain manufacturing environments. The studies show that AR for training can be highly effective, time-efficient and assures trainees learn the required skills. Furthermore, it has also been shown to allow providing feedback, which is a key factor in the learning process [9].

Compared to traditional training, AR avoids the inconvenience of information detached from the equipment, which forces trainees to switch their attention between the instructions and the subassembly [4]. AR-based training systems can combine real experiences with virtual instructions and guidance. Guidance is often provided through interactive checklists, to assure each step is followed. The AR system can potentially recognise steps carried out incorrectly and can alert the user, preventing him/her from continuing the procedure unless the error is fixed [10]. Further instructions can be provided if the tasks are performed wrongly [3].

Different levels of guidance, e.g. according to the trainees' level, can be provided using Indirect Visual Aids. The user can decide whether to see further information, whose availability is represented by an annotation or an icon. This choice is not available when using Direct Visual Aids: 3D animations or other information are directly superimposed on the product [6].

2.2. Research gaps

There is wide literature on AR applications for training processes. However, no publication was found on applications developed for manufacturers of mobile elevated work platforms. The cherry picker assembly processes and components are specific to the context, and they need to be studied and explored to understand if AR can support and improve training processes. Furthermore, training depends significantly on human factors and the context of application; a research study is required to develop an effective AR solution for the manual assembly operations in manufacturing.

3. Methodology

The following methodology was applied to achieve the aim of the study [11]. The project was divided into five phases, shown in Figure 3, and the key stages are explained in the following sub-sections:

- Project and problem definition
- Solution requirements identification
- Solution design
- Solution development
- Tool's validation and benefits assessment

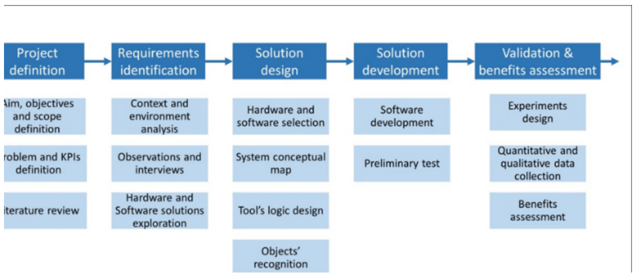

Fig. 1. Research methodology

3.1. Solution requirements identification

Interviews and observations at the Company shop-floor allowed to perform the context analysis and gather data on the different training delivery methods. Three days' of visits enabled to interview the Production Manager, two Line Managers, four expert technicians and two new employees. The identified requirements are presented in Table 1.

Table 1. Requirements identification.

Requirements	Way of measurement
Functional requirements:	
Complete and trainer independent guidance to operators.	Number of help request during the process.
Feedback provision.	Number of errors detected after the process completion.
Knowledge transfer.	Assessment questionnaire results.
Faster learning process.	Time to perform the assembly process.

Other requirements:	
Intuitive and usable tool.	Number of help requests related to the tool.
Precise and accurate information displayed.	Number of times operators ask for clarifications.
Possibility to work comfortably.	Qualitative questionnaire on AR experience.

3.2. Solution design and development

A number of technological approaches that were suitable to implement the requirements were identified. The choice was driven by: tools' advantages/disadvantages, integration between hardware and software and availability at Cranfield.

The solution was developed by transferring the concept and the logical flow into Unity, using C# as a programming language. AR functionalities were introduced through Vuforia. During the tool development, trials were made for the objects, images and target recognition. By working with the elements that were new to Vuforia, it was not possible to know beforehand which solution would have worked better. The production factors that influenced the design of the AR solution are explained in Table 2.

Table 2. Training bay and production line factors.

	Final product goes directly to the quality check.	Final product goes to the following station. Risk of adding value to a machine with quality defects due to inexperienced workers.
	No productivity pressures.	Productivity pressure.
	Possibility to assemble the whole machine, gaining knowledge in every aspect.	Specific knowledge limited to one station within the line.
nmon ts	General principles, not machine-specific.	Machine-specific knowledge, which allows having operators immediately available to work.
	Simpler components and operations.	Components' complexity depends on the line.
	One operator working.	Usually, more than one operator working.
	Operators start from zero. Most time-demanding scenario.	Operators with experience, whose training necessities vary greatly.
n ts	• Shadow board and tools' position • Possibility to familiarise with the machines, stations layout and tools. • Knowledge reusable on other lines • Resources (Raw material, SOPs, tools)	

4. Developed solution for AR in training in manufacturing

The AR solution was developed for training on the assembly of hydraulic hoses to the relative valve (Fig 7). They are present on each cherry picker, and the valve only varies in size and number of hoses, but the principle to fit hoses remains the same. First, the operator picks the tools on the shadow board. Each shadow board within the factory has the same tools' disposition. The operator brings the tools nearby the working area and then starts the assembly. Eleven hoses have to be fitted to the valve and to be tied together. The hoses' fitting order is important, to avoid difficulties in accessing the back joints later. The operator removes a cap from the joint and picks the hose to fit. Before fitting the first hose, the operator needs to calibrate the torque wrench. He/she then half-screws the hose manually and then torques it. The operator must ensure that the tool clicks, and can use a spanner to assist in this process. He/she then marks the conjunction according to the Company's colour code. The same operations are performed iteratively for each hose. Hoses are then tied: two of them on the left side and all the other ones on the right side. The torque wrench needs to be brought back to zero and put back to the shadow board with all the other tools.

The input to the developed AR system is 1) process instructions, 2) hardware and software, and 3) real world context. The output from the system is 1) step by step guidance, 2) feedback on operations, and 3) feedback on timing. An overview of the system is presented in Figure 2.

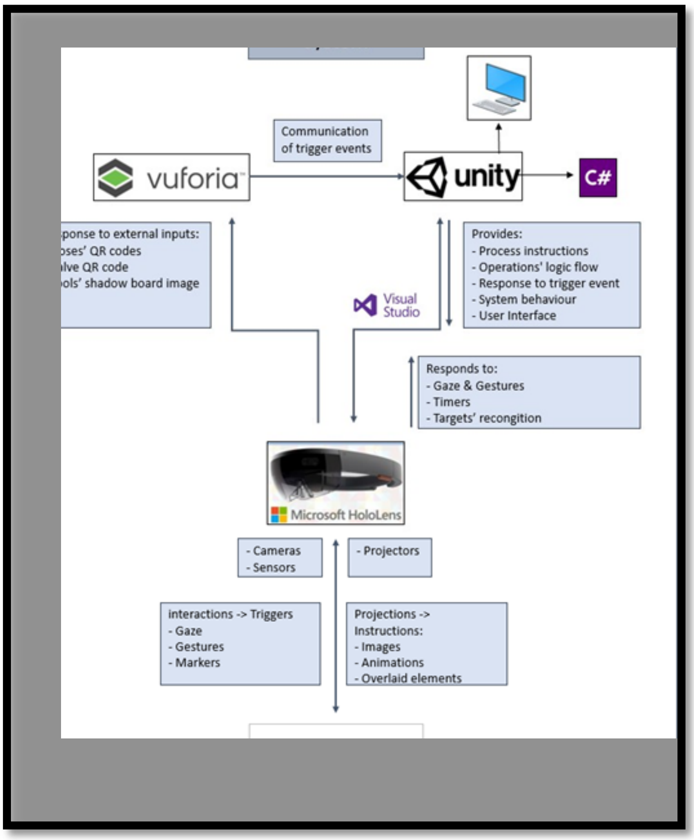

Fig. 2. AR System overview

As shown in Figure 3, the process was divided into 15 sub-processes: tools' picking, each hose fitting (11), hoses tie and tools' replacement on the shadow board. For each step, instructions' images and information were defined. Figure 3 shows the sequence logic of instructions'. First, a picture of the outcome is displayed. When the operator is ready to work, he/she can press the button and instructions are provided. In the AR system, there are three possible ways of moving forward: 1) a timer, if no interaction with the external environment is required, 2) the Vuforia recognition, when overlaid information is displayed and 3) the "Resume Instructions" button. After, the user has the empty field of view (FOV) to work without visual interferences; two side buttons are available: “Tap for instructions”, to go back to the same set of instructions, and “Finished”, to proceed further. The next step’s instructions are then displayed. At the end of the sub-process, an image of the work completed is displayed to allow user to check if the task was carried out correctly. When all the steps of a sub-process are completed, the system proceeds to the next sub- process.

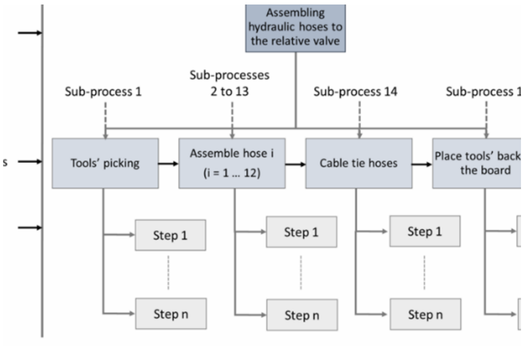

Fig. 3. Training process breakdown

Instructions are progressively reduced for similar or identical operations to enhance the learning process. First, they are fully displayed, then guidance is gradually reduced and from the third time onwards they are provided with fewer details. Full instructions are still available if requested.

4.1. User interface

In the application, there are three user interfaces:

The “Main interface” is used at the beginning and at the end of each sub- process. It shows the sub-process completed and allows acknowledgement. An example is displayed in Figure 4.

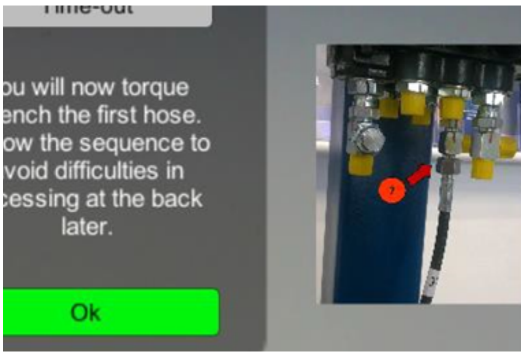

Fig. 4. "Main interface" - example

The “Instructions interface”, displayed in Figure 5, shows the instructions. The “Side interface”, showed in Figure 6, leaves the Field of View empty. In this process holograms are overlaid dynamically based on the movements of the hose.

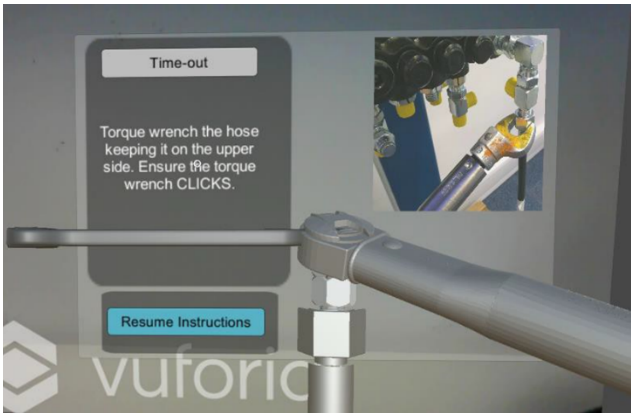

Fig. 5. An example instruction

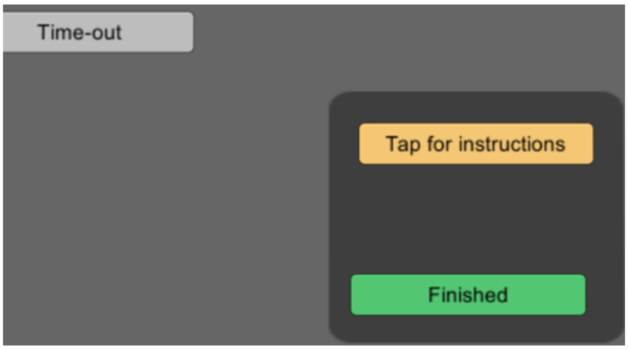

Fig. 6. Side interface

5. Validation

The application development was first deployed in the hardware device and tested at Cranfield AR Laboratory with students, who provided feedback. A preliminary validation session was carried out at the case company too. Testers first followed the tutorial on HoloLens and then performed the process with the AR application. Initial feedback was used to improve the application before the final validation.

Final validation experiments were run at Cranfield AR Laboratory by comparing the performances of two groups. The first group was asked to perform the process following the SOPs, while the second one used the AR instructions. The groups were defined according to the following criteria, to minimise the influence on the outcome of the analysis: experience with assembly operations, experience with AR and age. A stand that could hold the component in the right position was designed, as demonstrated in Figure 7.

Quantitative data from validation was collected through observations, and the use of the AR tool. A test to assess the learning level and a questionnaire to gather qualitative feedback on the AR experience were developed. Benefits of AR were assessed by comparing the performances of the two groups. The test was designed to evaluate if the system is an assistance system in the work environment rather than assess the level of learning through the system.

5.1. Experimental context

Validation data was collected about: the whole process time, the tools' picking time, users' error rate and the number of help requests. The tutorial on learning gestures in HoloLens took approximately 5 minutes and the pre-training application took 3 minutes. Their impact on time performances would not have provided a realistic scenario since they are undertaken only once and should be considered when comparing the whole training process. Table 3 and Table 4 show an overview of the participants of the two user groups. Factors influencing performances for assembly operations were considered, among which experience was the most relevant. Other factors, such as motivation, tiredness, stress and language difficulties were not considered, assuming that the students that volunteered were motivated, not in a stressful situation and no tired, since experiments were scheduled according to users' preferences. Language barriers were avoided by explaining the specific terminologies to each user at the beginning and thanks to the visual aids specifically introduced into the tool. Groups were defined according to users' preferences, and experiences. All users were Cranfield students with an engineering background. Information about experience with AR was irrelevant for the second group, while it was valuable to compare performances within the group that performed the process with the AR.

Table 3. Participants with AR.

Age		AR experience		Assembly experience	
< 20	0	Yes	2	Yes	1
20-30	5	Partial	2	Partial	0

Table 4. Experiments with SOPs.

< 20	0	Yes	-	Yes	1
20-30	5	Partial	-	Partial	0
> 30	0	No	-	No	4

The 3D model of the demonstrator, valve stand, was not available since it belonged to an old cherry picker model. This machine is the only one assembled at the training bay.

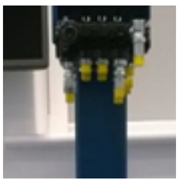

Fig. 7. Case example: Valve stand

When developing the 3D model, the reasons that prevented a good and stable object recognition, obtainable in other situations with HoloLens, were studied. Vuforia application was designed to work with consumer products, with opaque and rigid parts. Hoses' shape and features were very similar one to another. Therefore, Vuforia systems could not distinguish them according to their external characteristics. It was decided to introduce cylindrical markers, supported by Vuforia. The software takes in input as the flat image, the cylinder diameter and the height of the image.

5.2. Experimental results

The overall trend shows that AR required less assembly time for each fitting, except for the first and the second hose. Main differences were registered for the first hose and for the third hose fitting times (Figure 8). The average number of errors in the process decreased from 3 (SOPs) to 1.2 (AR).

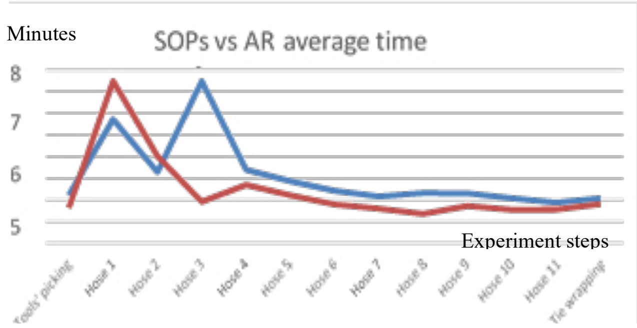

Fig. 8. Experimental results: AR vs SOPs

Users following the AR instructions, on average, performed the process with 22% less time (8 minutes), as shown in Table 5. Also, time to pick the tools was reduced by 26 %. Thus, the tool brought an overall improvement on the time needed to perform the process and complete the tasks. The standard deviation of time for SOPs users was 3.06 as opposed to 1.85 with AR. This indicates the reducing effect of variation in time.

Table 5. Time results: AR benefit assessment.

ssembly time			
verage hoses ssembly time	35.9 min	28 min	22
verage tools' picking time	2.2 min	1.6 min	26

Table 6. KPIs results and benefits assessment.

	SOPs	AR	Improver
Average error rate	2.6	1.2	≈ 5
Average number of help requests for the process	3	1	67
Questionnaire results	4.2 / 7	6.6 / 7	≈ 3

The results showed improvement of average performances. The standard deviation for number of help requests reduced from 0.98 (SOPs) to 0.75 (AR). The error rate and number of help requests for the process decreased, while the questionnaire results improved. SOPs users' average questionnaire results were greatly influenced by one user that performed way worse than the others (3 correct answers out of 7), while other users answered correctly to either 6 or 7 questions (Table 6).

5.3. Qualitative results

The results (from 10 people) of the questionnaire on the AR experience are displayed in Table 7. On average, people did not experience discomfort or a headache due to HoloLens and the AR experience was evaluated positively. Also, the learning level was perceived to be high.

Table 7. AR experience questionnaire results.

ons	Average answer
sickness (0 = none; 4 = extremely high)	0.4
che (0 = none; 4 = extremely high)	0.4
erience evaluation (0 = extremely bad; 4 = ely good)	3
ed learning level (0 = none; 4 = extremely	3.4
t (0 = extremely bad; 4 = extremely good)	2.8

Other qualitative questions were asked, and on average, the worst thing was clicking on buttons, while the user interface (images and animations) and the hoses recognition feature were considered highly. Most of the people (7 out of 10) believed that AR could enable a completely independent training process. Validation's results showed improvements for training delivered through the AR tool compared to the traditional way. Questionnaire results showed that the learning level improved.

In the validation, a limited amount of data was collected due to time constraints. The improvements by AR should be demonstrated with a greater number of users.

6. Discussion and conclusions

The aim of the project, to develop and validate an AR demonstrator, to demonstrate the possibility of introducing AR for training within the cherry picker manufacturing context was achieved. The experimental results showed improvements in performances, which should be studied further through validation at the case company. Despite the difficulties related to recognising the components, the case company environment is suitable for introducing the AR application that can potentially bring benefits according to Company's KPIs. The AR tool was introduced on the shop-floor during the preliminary validation and operators used it successfully.

The application was developed only on a small part of the assembly procedure; further difficulties may arise when and if applying the technology to the whole training. The size of the machines could impede the possibility of using HoloLens for every step, due to the limited FOV and the length of the process that could create discomfort to the users. The technology could, therefore be introduced only on certain parts of the process, such as the most complex tasks or the most difficult to learn for the operators. The proposed solution allows gaining benefits brought by AR and reducing the time necessary to develop the application and relative costs. The focused use of AR could reduce the risk of discomfort for users in the long usage scenario and the environment would not need to be entirely prepared, reducing the time dedicated to this activity. Technical knowledge could be transmitted through AR, while the human contact with other operators during other parts of the training would allow the transfer of tacit knowledge.

Future work in AR based training is needed in adaptive registration and tracking based on the context and the skills of the personnel. Furthermore, there has to be multiple runs of the same AR process with at least one time interruption to ensure the proof of learning effects. Future work has to also clarify if the sub-process has to be finalized correctly, or was there the opportunity to terminate a sub-process with an error.

Acknowledgements

The authors would like to acknowledge the collaborating organisation. This research was partially supported by the Engineering and Physical Sciences Research Council through the Through-life Engineering Services Centre (EP/R032718/1).

References

[1] Webel, S., Bockholt, U., Engelke, T., Gavish, N., Olbrich, M., & Preusche, C. An augmented reality training platform for assembly and maintenance skills. *Robotics and Autonomous Systems* 2013: *61*(4): 398–403.

[2] Nee, A. Y. C., Ong, S. K., Chryssolouris, G., & Mourtzis, D. Augmented reality applications in design and manufacturing. *CIRP Annals - Manufacturing Technology*, 2012: *61*(2): 657–679.

[3] Pathomaree, N., & Charoenseang, S. Augmented reality for skill transfer in assembly task. *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication 2005*: 500–504.

[4] Ong, S. K., Yuan, M. L., & Nee, A. Y. C. Augmented reality applications in manufacturing: A survey. *International Journal of Production Research* 2008: *46*(10): 2707–2742.

[5] Palmarini, R., Erkoyuncu, J. A., & Roy, R. An Innovative Process to Select Augmented Reality (AR) Technology for Maintenance. Procedia CIRP 2017:59: 23–28.

[6] Webel, S., Bockholt, U., & Engelke, T. Recent Trends of Mobile Collaborative Augmented Reality Systems 2011: 69–82.

[7] Krevelen, D. W. F. Van, & Poelman, R.. A Survey of Augmented Reality Technologies, Applications and Limitations, The International Journal of Virtual Reality 2010: *9*(2), 1–21.

[8] Mura, M. D., Dini, G., & Failli, F. An Integrated Environment Based on Augmented Reality and Sensing Device for Manual Assembly Workstations. *Procedia CIRP* 2016: *41*, 340–345.

[9] Wang, X., Ong, S. K., & Nee, A. Y. C. A comprehensive survey of augmented reality assembly research. Advances in Manufacturing 2016: 4(1): 1– 22.

[10] Tatić, D., & Tešić, B. The application of augmented reality technologies for the improvement of occupational safety in an industrial environment. Computers in Industry 2017: 85: 1–10.

[11] Standard, I. (2011). INTERNATIONAL STANDARD ISO / IEC / IEEE Systems and software engineering — engineering, 2011.

2019-06-24

Developing an augmented reality based training demonstrator for manufacturing cherry pickers

Ferrati, Francesca

Elsevier

Ferrati F, Erkoyuncu JA, Court S. (2019) Developing an augmented reality based training demonstrator for manufacturing cherry pickers. Procedia CIRP, Volume 81, 2019, pp. 803-808

https://doi.org/10.1016/j.procir.2019.03.203